Peripheral Nervous System (PNS)

- PNS – all neural structures outside the brain and spinal cord
- Includes: sensory receptors, peripheral nerves, associated ganglia, and motor endings
- Provides links to and from the external environment

Sensory Receptors

- Structures specialized to respond to stimuli
- Activation of sensory receptors results in depolarizations that trigger impulses to the CNS
- The realization of these stimuli, sensation and perception, occur in the brain

Receptor Classification by Stimulus

- Mechanoreceptors – respond to touch, pressure, vibration, stretch, and itch
- Thermoreceptors – sensitive to changes in temperature
- Photoreceptors – respond to light energy (e.g., retina)
- Chemoreceptors – respond to chemicals (e.g., smell, taste, changes in blood chemistry)
- Nociceptors – sensitive to pain-causing stimuli

Receptor Class by Location: Exteroceptors

- Respond to stimuli arising outside the body
- Found near the body surface
- Sensitive to touch, pressure, pain, and temperature
- Includes the special sense organs

Receptor Class by Location: Interoceptors

- Respond to stimuli arising within the body
- Found in internal viscera and blood vessels
- Sensitive to chemical changes, stretch, and temperature changes

Receptor Class by Location: Proprioceptors

- Respond to degree of stretch of the organs they occupy
- Found in skeletal muscles, tendons, joints, ligaments, and connective tissue coverings of bones and muscles
- Constantly “advise” the brain of one’s movements

Receptor Classification by Structure

- Receptors are structurally classified as either simple or complex
- Most receptors are simple and include encapsulated and unencapsulated varieties
- Complex receptors are special sense organs

Simple Receptors: Unencapsulated

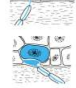
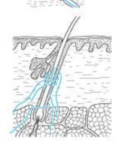
- Free dendritic nerve endings
- Merkel discs
- Root hair plexuses

Simple Receptors: Encapsulated

- Meissner's corpuscles and Krause's end bulbs
- Pacinian corpuscles
- Muscle spindles, Golgi tendon organs, and Ruffini's corpuscles
- Joint kinesthetic receptors

Simple Receptors: Unencapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function

Anatomical class (structure)	*Illustration*	*Functional classes according to location (L) and stimulus type (S)*	*Body location*
Unencapsulated Free dendritic nerve endings of sensory neurons		L: Exteroceptors, interoceptors, and proprioceptors S: Nociceptors (pain), thermoreceptors (heat and cold), possible mechanoreceptors (pressure)	Most body tissues; most dense in connective tissues (ligaments, tendons, dermis, joint capsules, periostea) and epithelia (epidermis, cornea, mucosae, and glands)
Modified free dendritic endings: Merkel discs		L: Exteroceptors S: Mechanoreceptors (light pressure); slowly adapting	Basal layer of epidermis of skin
Root hair plexuses		L: Exteroceptors S: Mechanoreceptors (hair deflection); rapidly adapting	In and surrounding hair follicles

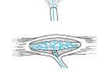
Simple Receptors: Encapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function

Anatomical class (structure)	*Illustration*	*Functional classes according to location (L) and stimulus type (S)*	*Body location*
Encapsulated Meissner's corpuscles		L: Exteroceptors S: Mechanoreceptors (light pressure, discriminative touch, vibration of low frequency)	Dermal papillae of hairless skin, particularly nipples, external genitalia, fingertips, soles of feet, eyelids
Krause's end bulbs		L: Exteroceptors S: Mechanoreceptors (probably modified Meissner's corpuscles)	Connective tissue of mucosae (mouth, conjunctiva of eye) and of hairless skin near body openings (lips)

Simple Receptors: Encapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function *(continued)*

Anatomical class (structure)	*Illustration*	*Functional classes according to location (L) and stimulus type (S)*	*Body location*
Pacinian corpuscles		L: Exteroceptors, interoceptors, and some proprioceptors S: Mechanoreceptors (deep pressure, stretch, vibration of high frequency); rapidly adapting	Subcutaneous tissue of the skin; periostea, mesentery, tendons, ligaments, joint capsules, most abundant on fingers, soles of feet, external genitalia, nipples
Ruffini's corpuscles		L: Exteroceptors and proprioceptors S: Mechanoreceptors (deep pressure and stgretch); slowly adapting	Deep in dermis, hypodermis, and joint capsules

Simple Receptors: Encapsulated

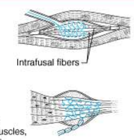
TABLE 13.1	General Sensory Receptors Classified by Structure and Function *(continued)*		
Anatomical class (structure)	*Illustration*	*Functional classes according to location (L) and stimulus type (S)*	*Body location*
Muscle spindles		L: Proprioceptors S: Mechanoreceptors (muscle stretch)	Skeletal muscles, particularly those of the extremities
Golgi tendon organs		L: Proprioceptors S: Mechanoreceptors (tendon stretch)	Tendons
Joint kinesthetic receptors (Pacinian and Ruffini corpuscles, free dendritic endings, and receptors resembling Golgi tendon organs)		L: Proprioceptors S: Mechanoreceptors and nociceptors	Joint capsules of synovial joints

Table 13.1.4

Chemical Senses

- Chemical senses – gustation (taste) and olfaction (smell)
- Chemoreceptors respond to chemicals in aqueous solution
  - Taste – to substances dissolved in saliva
  - Smell – to substances dissolved in fluids of the nasal membranes

Taste Buds

- The 10,000 or so taste buds are mostly found on the tongue
- Found in papillae of the tongue mucosa
- Papillae come in three types: filiform, fungiform, and circumvallate
- Fungiform and circumvallate papillae contain taste buds

Taste Buds

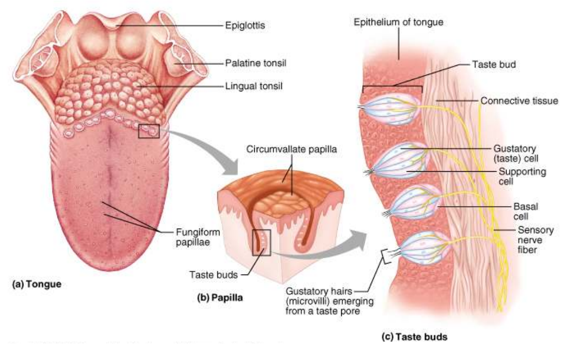


Figure 13.2a-c

Anatomy of a Taste Bud

- Each gourd-shaped taste bud consists of three major cell types
  - Supporting cells – insulate the receptor
  - Basal cells – dynamic stem cells
  - Gustatory cells – taste cells

Anatomy of a Taste Bud

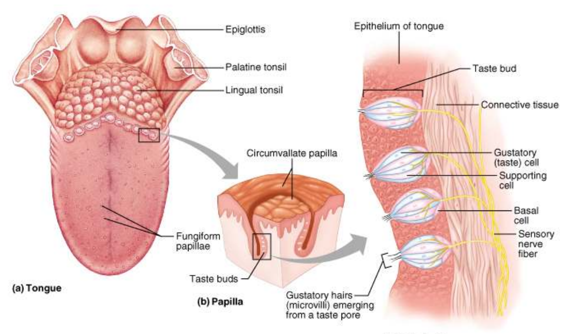


Figure 13.2a-c

Taste Sensations

- There are four basic taste sensations
  - Sweet – sugars, saccharin, alcohol, and some amino acids
  - Salt – metal ions
  - Sour – hydrogen ions
  - Bitter – alkaloids such as quinine and nicotine

Physiology of Taste

- In order to be tasted, a chemical:
  - Must be dissolved in saliva
  - Contact gustatory hairs
- Binding of the food chemical:
  - Depolarizes the taste cell membrane, releasing neurotransmitter
  - Initiates a generator potential that elicits an action potential

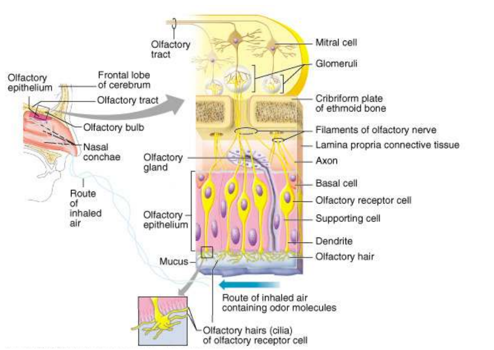
Gustatory Pathways

- Cranial Nerves VII and IX carry impulses from taste buds to the solitary nucleus of the medulla
- These impulses then travel to the thalamus, and from there fibers branch to the:
  - Gustatory cortex (taste)
  - Hypothalamus and limbic system (appreciation of taste)

Sense of Smell

- The organ of smell is the olfactory epithelium, which covers the superior nasal conchae
- Olfactory receptor cells are bipolar neurons with radiating olfactory cilia
  - They are surrounded and cushioned by supporting cells
- Basal cells lie at the base of the epithelium

Sense of Smell



Olfactory Pathway

- Olfactory receptor cells synapse with mitral cells
- Glomerular mitral cells process odor signals
- Mitral cells send impulses to:
  - The olfactory cortex
  - The hypothalamus, amygdala, and limbic system

Eye and Associated Structures

- 70% of all sensory receptors are in the eye
- Photoreceptors – sense and encode light patterns
- The brain fashions images from visual input
- Accessory structures include:
  - Eyebrows, eyelids, conjunctiva
  - Lacrimal apparatus and extrinsic eye muscles

Eyebrows

- Coarse hairs that overlie the supraorbital margins
- Functions include:
  - Shading the eye
  - Preventing perspiration from reaching the eye
- Orbicularis muscle – depresses the eyebrow
- Corrugator muscle – move the eyebrow medially

Palpebrae (Eyelids)

- Protect the eye anteriorly
- Palpebral fissure – separates eyelids
- Canthi - medial and lateral angles (commissures)
- Lacrimal caruncle – contains glands that secrete a whitish, oily secretion ("Sandman's eye sand")
- Tarsal plates of connective tissue support the eyelids internally
- Levator palpebrae superioris – gives the upper eyelid mobility

Palpebrae (Eyelids)

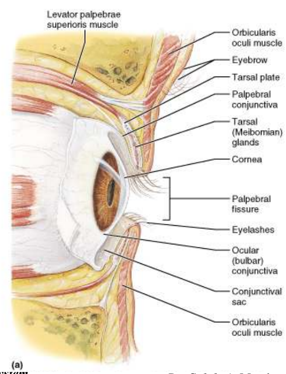


Figure 13.5a

Accessory Structures of the Eye

- Eyelashes:
  - Project from the free margin of each eyelid
  - Initiate reflex blinking
- Lubricating glands associated with the eyelids
  - Meibomian glands and sebaceous glands
  - Ciliary glands

Conjunctiva

- Transparent membrane that:
  - Lines the eyelids as the palpebral conjunctiva
  - Covers the whites of the eyes as the ocular conjunctiva
  - Lubricates and protects the eye

Conjunctiva

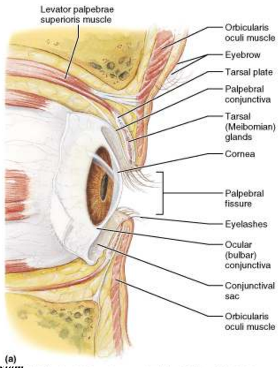


Figure 13.5a

Lacrimal Apparatus

- Consists of the lacrimal gland and associated ducts
- Lacrimal glands secrete tears
- Tears:
  - Contain mucus, antibodies, and lysozyme
  - Enter the eye via superolateral excretory ducts
  - Exit the eye medially via the lacrimal punctum
  - Drain into the nasolacrimal duct

Lacrimal Apparatus

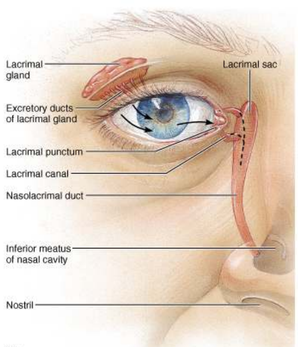


Figure 13.5b

Extrinsic Eye Muscles

- Six straplike extrinsic eye muscles:
  - Enable the eye to follow moving objects
  - Maintain the shape of the eyeball
- The two basic types of eye movements are:
  - Saccades – small, jerky movements
  - Scanning movements – tracking an object through the visual field

Extrinsic Eye Muscles

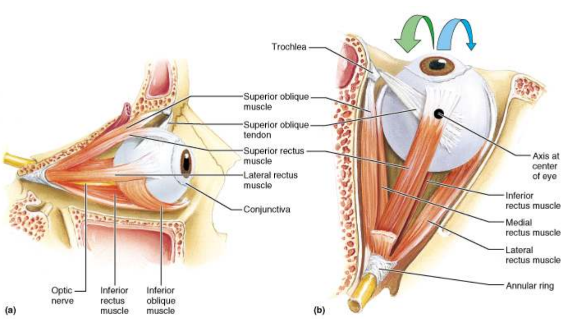


Figure 13.6a, b

Summary of Cranial Nerves and Muscle Action

- Names, actions, and cranial nerve innervation of the extrinsic eye muscles

Name	Action	Controlling cranial nerve
Lateral rectus	Moves eye laterally	VI (abducens)
Medial rectus	Moves eye medially	III (oculomotor)
Superior rectus	Elevates eye	III (oculomotor)
Inferior rectus	Depresses eye	III (oculomotor)
Inferior oblique	Elevates eye and turns it laterally	III (oculomotor)
Superior oblique	Depresses eye and turns it laterally	IV (trochlear)

(c)

Figure 13.6c

Structure of the Eyeball

- A slightly irregular hollow sphere with anterior and posterior poles
- The wall is composed of three tunics – fibrous, vascular, and sensory
- The internal cavity is fluid filled with humors – aqueous and vitreous
- The lens separates the internal cavity into anterior and posterior segments

Structure of the Eyeball

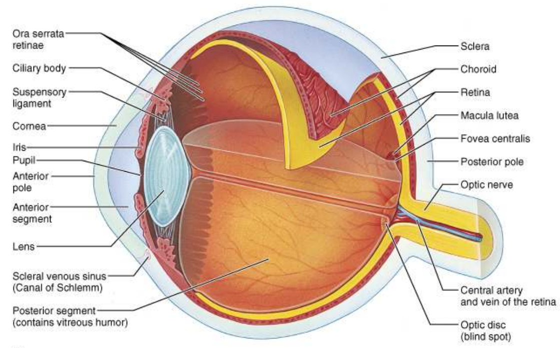


Figure 13.7a

Fibrous Tunic

- Forms the outermost coat of the eye and is composed of:
  - Opaque sclera (posterior)
  - Clear cornea (anterior)
- Sclera – protects the eye and anchors extrinsic muscles
- Cornea – lets light enter the eye

Vascular Tunic (Uvea): Choroid Region

- Has three regions: choroid, ciliary body, and iris
- Choroid region
  - A dark brown membrane that forms the posterior portion of the uvea
  - Supplies blood to all eye tunics
  - Prevents light from scattering and reflecting within the eye

Vascular Tunic: Ciliary Body

- A thickened ring of tissue surrounding the lens
- Composed of smooth muscle bundles (ciliary muscles)
- Anchors the suspensory ligament that holds the lens in place

Vascular Tunic: Iris

- The colored part of the eye
- Pupil – central opening of the iris
- Regulates the amount of light entering the eye during:
  - Close vision and bright light – pupils constrict
  - Distant vision and dim light – pupils dilate
  - Changes in emotional state – pupils dilate when the subject matter is appealing or requires problem solving skills

Vascular Tunic: Iris

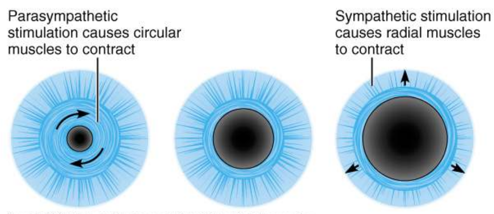


Figure 13.8

Sensory Tunic: Retina

- A delicate two-layered membrane
- Pigmented layer – the outer layer that absorbs light and prevents its scattering
- Neural layer, which contains:
  - Photoreceptors that transduce light energy
  - Bipolar cells and ganglion cells
  - Amacrine and horizontal cells

Sensory Tunic: Retina

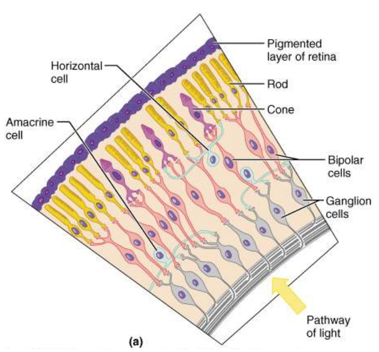


Figure 13.9a

The Retina: Ganglion Cells and the Optic Disc

- Ganglion cell axons:
  - Run along the inner surface of the retina
  - Leave the eye as the optic nerve
- The optic disc:
  - Is the site where the optic nerve leaves the eye
  - Lacks photoreceptors (the blind spot)

The Retina: Ganglion Cells and the Optic Disc

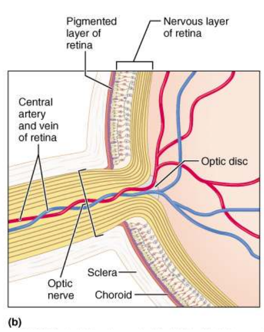


Figure 16.9b

The Retina: Photoreceptors

- Rods:
  - Respond to dim light
  - Are used for peripheral vision
- Cones:
  - Respond to bright light
  - Have high-acuity color vision
  - Are found in the macula lutea
  - Are concentrated in the fovea centralis

Blood Supply to the Retina

- The neural retina receives its blood supply from two sources
  - The outer third receives its blood from the choroid
  - The inner two-thirds are served by the central artery and vein
- Small vessels radiate out from the optic disc and can be seen with an ophthalmoscope

Internal Chambers and Fluids

- The lens separates the internal eye into anterior and posterior segments
- The posterior segment is filled with a clear gel called vitreous humor that:
  - Transmits light
  - Supports the posterior surface of the lens
  - Holds the neural retina firmly against the pigmented layer
  - Contributes to intraocular pressure

Anterior Segment

- Composed of two chambers
  - Anterior – between the cornea and the iris
  - Posterior – between the iris and the lens
- Aqueous humor
  - A plasmalike fluid that fills the anterior segment
  - Drains via the canal of Schlemm
  - Supports, nourishes, and removes wastes

Anterior Segment

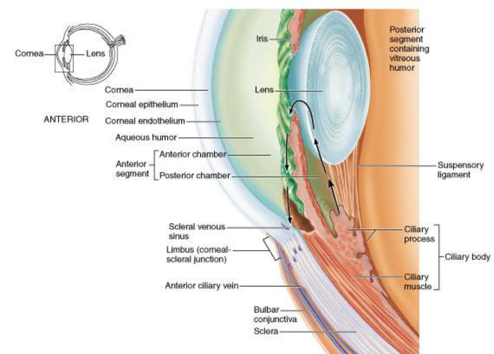


Figure 13.11

The Lens

- A biconvex, transparent, flexible, avascular structure that:
  - Allows precise focusing of light onto the retina
  - Is composed of epithelium and lens fibers
- Lens epithelium – anterior cells that differentiate into lens fibers
- Lens fibers – cells filled with the clear protein crystalline
- With age, the lens becomes more compact and dense and loses its elasticity

Light

- Electromagnetic radiation – all energy waves from short gamma rays to long radio waves
- Our eyes respond to a small portion of this spectrum, called the visible spectrum
- Different cones in the retina respond to different wavelengths of the visible spectrum

Light

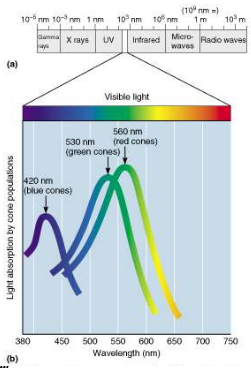


Figure 13.12

Refraction and Lenses

- When light passes from one transparent medium to another its speed changes and it refracts (bends)
- Light passing through a convex lens (as is in the eye) is bent so that the rays converge to a focal point
- When a convex lens forms an image, the image is upside down and reversed right to left

Refraction and Lenses

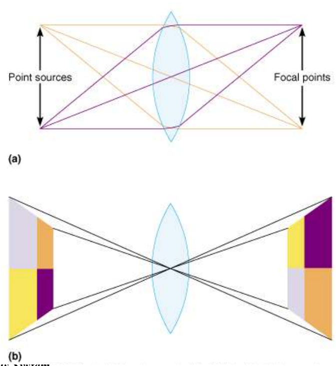


Figure 13.13

Focusing Light on the Retina

- Pathway of light entering the eye: cornea, aqueous humor, lens, vitreous humor, and the neural layer of the retina to the photoreceptors
- Light is refracted:
  - At the cornea
  - Entering the lens
  - Leaving the lens
- The lens curvature and shape allow for fine focusing of an image

Focusing for Distant Vision

- Light from a distance needs little adjustment for proper focusing
- Far point of vision – the distance beyond which the lens does not need to change shape to focus (20ft)

Focusing for Distant Vision

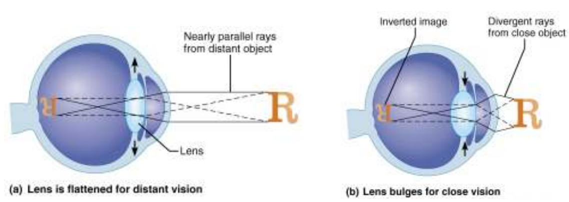


Figure 13.14

Focusing for Close Vision

- Close vision requires:
  - Accommodation – changing the lens shape by ciliary muscles to increase refractory power
  - Constriction – the pupillary reflex constricts the pupils to prevent divergent light rays from entering the eye
  - Convergence – medial rotation of the eyeballs toward the object being viewed

Problems of Refraction

- Emmetropic eye – normal eye with light focused properly
- Myopic eye (nearsighted) – the focal point is in front of the retina
  - Corrected with a concave lens
- Hyperopic eye (farsighted) – the focal point is behind the retina
  - Corrected with a convex lens

Photoreception: Functional Anatomy of Photoreceptors

- Photoreception – process by which the eye detects light energy
- Rods and cones contain visual pigments (photopigments)
  - Arranged in a stack of disklike infoldings of the plasma membrane that change shape as they absorb light

Photoreception: Functional Anatomy of Photoreceptors

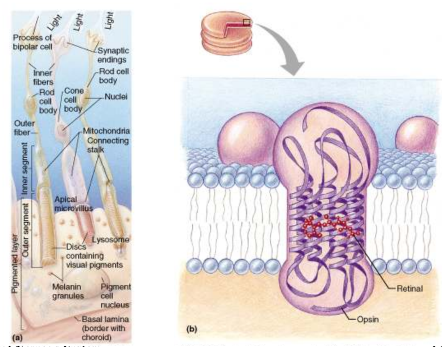


Figure 13.15

Rods

- Functional characteristics
  - Sensitive to dim light and best suited for night vision
  - Absorb all wavelengths of visible light
  - Perceived input is in gray tones only
  - Sum visual input from many rods feed into a single ganglion cell
  - Results in fuzzy and indistinct images

Cones

- Functional characteristics
  - Need bright light for activation (have low sensitivity)
  - Pigments that furnish a vividly colored view
  - Each cone synapses with a single ganglion cell
  - Vision is detailed and has high resolution

Chemistry of Visual Pigments

- Retinal – a light-absorbing molecule
  - Combines with opsins to form visual pigments
  - Similar to and is synthesized from vitamin A
  - Two isomers: 11-*cis* and all-*trans*
- Isomerization of retinal initiates electrical impulses in the optic nerve

Chemistry of Visual Pigments

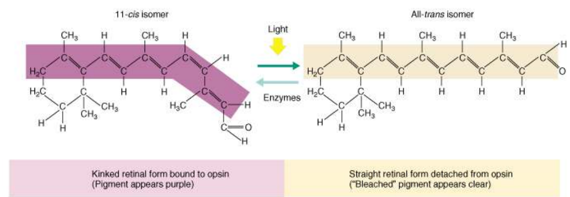


Figure 13.16

Excitation of Rods

- The visual pigment of rods is rhodopsin (opsin + 11-*cis* retinal)
- Light phase
  - Rhodopsin breaks down into all-*trans* retinal + opsin (bleaching of the pigment)
- Dark phase
  - All-*trans* retinal converts to 11-*cis* form
  - 11-*cis* retinal is also formed from vitamin A
  - 11-*cis* retinal + opsin regenerate rhodopsin

Excitation of Rods

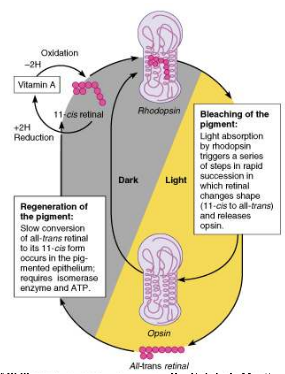


Figure 13.17

Excitation of Cones

- Visual pigments in cones are similar to rods (retinal + opsins)
- There are three types of cones: blue, green, and red
- Intermediate colors are perceived by activation of more than one type of cone
- The method of excitation is similar to rods

Adaptation

- Adaptation to bright light (going from dark to light) involves:
  - Dramatic decreases in retinal sensitivity – rod function is lost
  - Switching from the rod to the cone system – visual acuity is gained
- Adaptation to dark is the reverse
  - Cones stop functioning in low light
  - Rhodopsin accumulates in the dark and retinal sensitivity is restored

Visual Pathways

- Axons of retinal ganglion cells form the optic nerve
- Medial fibers of the optic nerve decussate at the optic chiasma
- Most fibers of the optic tracts continue to the lateral geniculate body of the thalamus
- Other optic tract fibers end in superior colliculi (initiating visual reflexes) and pretectal nuclei (involved with pupillary reflexes)
- Optic radiations travel from the thalamus to the visual cortex

Visual Pathways

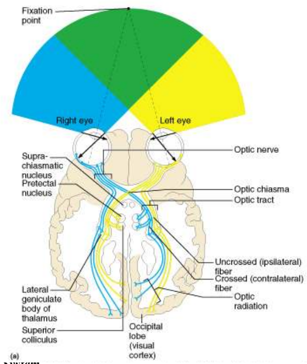


Figure 13.18

Depth Perception

- Achieved by both eyes viewing the same image from slightly different angles
- Three-dimensional vision results from cortical fusion of the slightly different images
- If only one eye is used, depth perception is lost and the observer must rely on learned clues to determine depth

Retinal Processing

- At synapses between depolarizing rods and a bipolar cell, the rods release neurotransmitter, which inhibits the bipolar cell
- At synapses between hyperpolarizing rods and a bipolar cell, neurotransmitter release stops
  - The bipolar cell produces EPSPs in the related ganglion cell and interacts with local retinal integrator cells
  - The result is a smeary picture
- Signals from cones feed directly into excitatory synapses on ganglion cells
  - The result is a sharp and clear color picture

Thalamic Processing

- The lateral geniculate nuclei of the thalamus:
  - Relay information on movement
  - Segregate the retinal axons in preparation for depth perception
  - Emphasize visual inputs from regions of high cone density
  - Sharpen the contrast information received by the retina

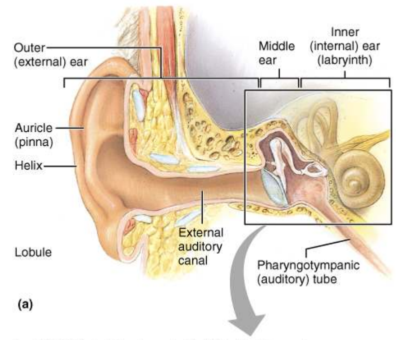
Cortical Processing

- Striate cortex processes
  - Basic dark/bright and contrast information
- Prestriate cortices (association areas) processes
  - Form, color, and movement
- Visual information then proceeds anteriorly to the:
  - Temporal, parietal, and frontal lobes – processes identification of objects

The Ear: Hearing and Balance

- The three parts of the ear are the inner, outer, and middle ear
- The outer and middle ear are involved with hearing
- The inner ear functions in both hearing and equilibrium
- Receptors for hearing and balance:
  - Respond to separate stimuli
  - Are activated independently

The Ear: Hearing and Balance



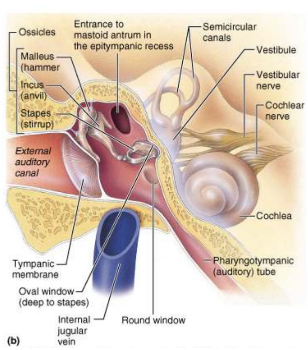
Outer Ear

- The auricle (pinna) is composed of:
  - The helix (rim)
  - The lobule (earlobe)
- External auditory canal
  - Short, curved tube filled with ceruminous glands
- Tympanic membrane (eardrum)
  - Thin connective tissue membrane that vibrates in response to sound
  - Transfers sound energy to the middle ear ossicles
  - Boundary between outer and middle ears

Middle Ear (Tympanic Cavity)

- A small, air-filled, mucosa-lined cavity
  - Flanked laterally by the eardrum
  - Flanked medially by the oval and round windows
- Epitympanic recess – superior portion of the middle ear
- Pharyngotympanic tube – connects the middle ear to the nasopharynx
  - Equalizes pressure in the middle ear cavity with the external air pressure

Middle Ear (Tympanic Cavity)



Ear Ossicles

- The tympanic cavity contains three small bones: the malleus, incus, and stapes
  - Transmit vibratory motion of the eardrum to the oval window
  - Dampened by the tensor tympani and stapedius muscles

Inner Ear

- Bony labyrinth
  - Tortuous channels worming their way through the temporal bone
  - Contains the vestibule, the cochlea, and the semicircular canals
  - Filled with perilymph
- Membranous labyrinth
  - Series of membranous sacs within the bony labyrinth
  - Filled with a potassium-rich fluid

Inner Ear

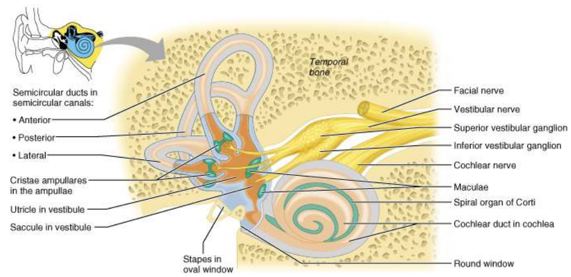


Figure 13.20

The Vestibule

- The central egg-shaped cavity of the bony labyrinth
- Suspended in its perilymph are two sacs: the saccule and utricle
- The saccule extends into the cochlea
- The utricle extends into the semicircular canals
- These sacs:
  - House equilibrium receptors in their maculae
  - Respond to gravity and changes in the position of the head

The Semicircular Canals

- Three canals that each define two-thirds of a circle and lie in the three planes of space
- Membranous semicircular ducts line each canal and communicate with the utricle
- The ampulla is the swollen end of each canal and it houses equilibrium receptors in a region called the *crista ampullaris*
- These receptors respond to angular movements of the head

The Semicircular Canals

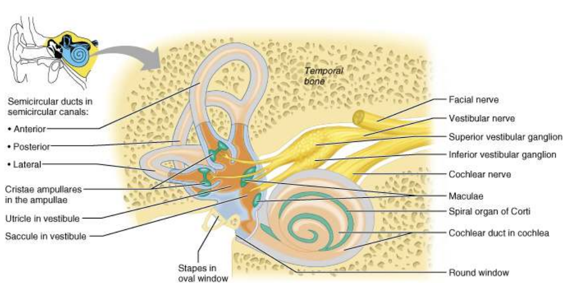


Figure 13.20

The Cochlea

- A spiral, conical, bony chamber that:
  - Extends from the anterior vestibule
  - Coils around a bony pillar called the *modiolus*
  - Contains the cochlear duct, which ends at the cochlear apex
  - Contains the organ of Corti (hearing receptor)

The Cochlea

- The cochlea is divided into three chambers
  - Scala vestibuli
  - Scala media
  - Scala tympani

The Cochlea

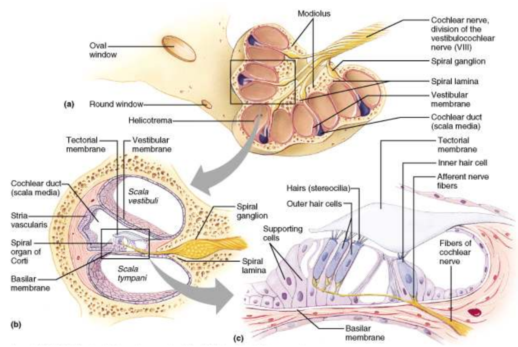


Figure 13.21

The Cochlea

- The scala tympani terminates at the round window
- The scalas tympani and vestibuli:
  - Are filled with perilymph
  - Are continuous with each other via the helicotrema
- The scala media is filled with endolymph

The Cochlea

- The “floor” of the cochlear duct is composed of:
  - The bony spiral lamina
  - The basilar membrane, which supports the organ of Corti
- The cochlear branch of nerve VIII runs from the organ of Corti to the brain

The Cochlea

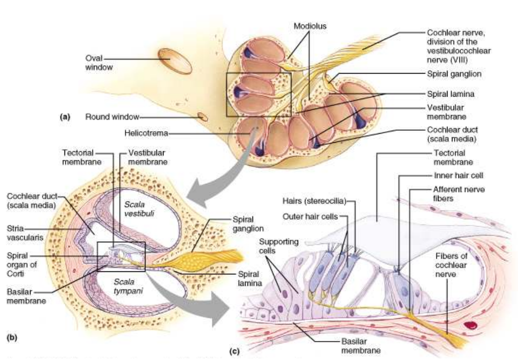


Figure 13.21

Properties of Sound

- Sound is:
  - A pressure disturbance originating from a vibrating object
  - Composed of areas of rarefaction and compression
  - Represented by a sine wave in wavelength, frequency, and amplitude

Properties of Sound

- Frequency – the number of waves that pass a given point in a given time
- Pitch – perception of different frequencies (we hear from 20–20,000 Hz)
- Amplitude – intensity of a sound measured in decibels (dB)
- Loudness – subjective interpretation of sound intensity

Properties of Sound

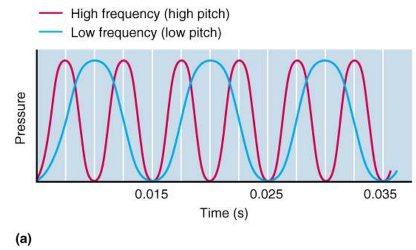


Figure 13.22a

Properties of Sound

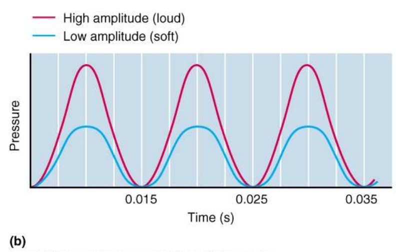


Figure 13.22b

Transmission of Sound to the Inner Ear

- The route of sound to the inner ear follows this pathway:
  - Outer ear – pinna to the auditory canal to the eardrum
  - Middle ear – malleus, incus, and stapes to the oval window
  - Inner ear – scala vestibuli and tympani to the cochlear duct
    - Stimulation of the organ of Corti

Resonance of the Basilar Membrane

- Sound waves of low frequency (inaudible):
  - Take the complete route through the perilymph to the round window
  - Do not excite hair cells
- Audible sound waves:
  - Penetrate through the cochlear duct
  - Vibrate the basilar membrane
  - Excite specific hair cells according to frequency of the sound

Resonance of the Basilar Membrane

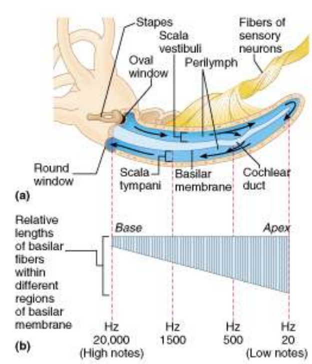


Figure 13.23

The Organ of Corti

- Composed of supporting cells and outer and inner hair cells
- Afferent fibers of the cochlear nerve attach to the base of hair cells
- The stereocilia (hairs):
  - Protrude into the endolymph
  - Touch the tectorial membrane

Excitation of Hair Cells in the Organ of Corti

- Bending cilia:
  - Opens mechanically-gated ion channels
  - Causes a graded potential and the release of a neurotransmitter (probably glutamate)
- The neurotransmitter causes cochlear fibers to transmit impulses to the brain, where sound is perceived

Excitation of Hair Cells in the Organ of Corti

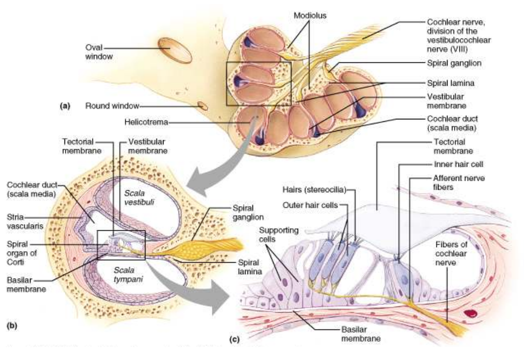


Figure 13.21

Auditory Pathway to the Brain

- Impulses from the cochlea pass via the spiral ganglion to the cochlear nuclei
- From there, impulses are sent to the:
  - Superior olivary nucleus
  - Inferior colliculus (auditory reflex center)
- From there, impulses pass to the auditory cortex
- Auditory pathways decussate so that both cortices receive input from both ears

Auditory Processing

- Pitch is perceived by:
  - The primary auditory cortex
  - Cochlear nuclei
- Loudness is perceived by:
  - Varying thresholds of cochlear cells
  - The number of cells stimulated
- Localization is perceived by the relative intensity and the relative timing

Deafness

- Conduction deafness – something hampers sound conduction to the fluids of the inner ear (e.g., impacted earwax, perforated eardrum, osteosclerosis of the ossicles)
- Sensorineural deafness – results from damage to the neural structures at any point from the cochlear hair cells to the auditory cortical cells
- Tinnitus – ringing or clicking sound in the ears in the absence of auditory stimuli
- Meniere's syndrome – labyrinth disorder that affects the cochlea and the semicircular canals causing vertigo, nausea, and vomiting

Mechanisms of Equilibrium and Orientation

- Vestibular apparatus – equilibrium receptors in the semicircular canals and vestibule
  - Maintain our orientation and balance in space
  - Vestibular receptors monitor static equilibrium
  - Semicircular canal receptors monitor dynamic equilibrium

Anatomy of Maculae

- Maculae – the sensory receptors for static equilibrium
  - Contain supporting cells and hair cells
  - Each hair cell has stereocilia and kinocilium embedded in the otolithic membrane
- Otolithic membrane – jellylike mass studded with tiny $CaCO_3$ stones called otoliths
- Utricular hairs respond to horizontal movement
- Saccular hair respond to vertical movement

Anatomy of Maculae

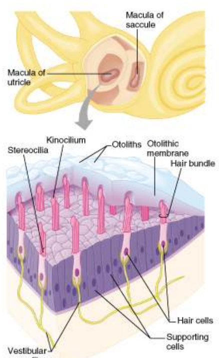


Figure 13.24

Effect of Gravity on Utricular Receptor Cells

- Otolithic movement in the direction of the kinocilia:
  - Depolarizes vestibular nerve fibers
  - Increases the number of action potentials generated
- Movement in the opposite direction:
  - Hyperpolarizes vestibular nerve fibers
  - Reduces the rate of impulse propagation
- From this information, the brain is informed of the changing position of the head

Crista Ampullaris and Dynamic Equilibrium

- The crista ampullaris (or crista):
  - Is the receptor for dynamic equilibrium
  - Is located in the ampulla of each semicircular canal
  - Responds to angular movements
- Each crista has support cells and hair cells that extend into a gelled mass called the cupula
- Dendrites of vestibular nerve fibers encircle the base of the hair cells

Crista Ampullaris and Dynamic Equilibrium

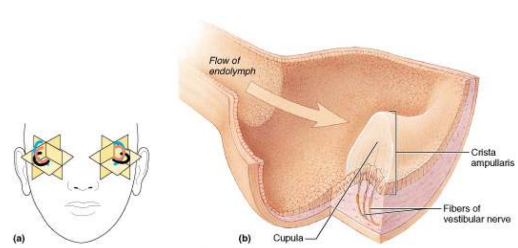


Figure 13.25

Balance and Orientation Pathways

- There are three modes of input for balance and orientation
  - Vestibular receptors
  - Visual receptors
  - Somatic receptors
- These receptors allow our body to respond reflexively

Structure of a Nerve

- Nerve – cordlike organ of the PNS consisting of peripheral axons enclosed by connective tissue

Structure of a Nerve

- Connective tissue coverings include:
  - Endoneurium – loose connective tissue that surrounds axons
  - Perineurium – coarse connective tissue that bundles fibers into fascicles
  - Epineurium – tough fibrous sheath around a nerve

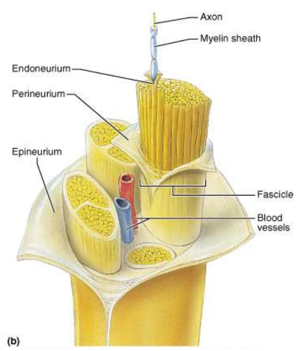


Figure 13.26b

Classification of Nerves

- Sensory and motor divisions
- Sensory (afferent) – carry impulse to the CNS
- Motor (efferent) – carry impulses from the CNS
- Mixed – sensory and motor fibers carry impulses to and from the CNS; most common type of nerve

Peripheral Nerves

- Mixed nerves – carry somatic and autonomic (visceral) impulses
- The four types of mixed nerves
  - Somatic afferent and somatic efferent
  - Visceral afferent and visceral efferent
- Peripheral nerves originate from the brain or spinal column

Regeneration of Nerve Fibers

- Damage to nerve tissue is serious because mature neurons are amitotic
- If the soma of a damaged nerve remains intact, damage can be repaired
- Regeneration involves coordinated activity among:
  - Macrophages – remove debris
  - Schwann cells – form regeneration tube and secrete growth factors
  - Axons – regenerate damaged part

Regeneration of Nerve Fibers

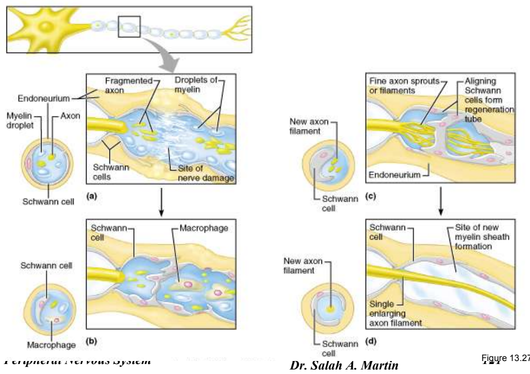


Figure 13.27

Cranial Nerves

- Twelve pairs of cranial nerves arise from the brain
- They have sensory, motor, or both sensory and motor functions.
- Each nerve is identified by a number (I through XII) and a name
- Four cranial nerves carry parasympathetic fibers that serve muscles and glands

Cranial Nerves

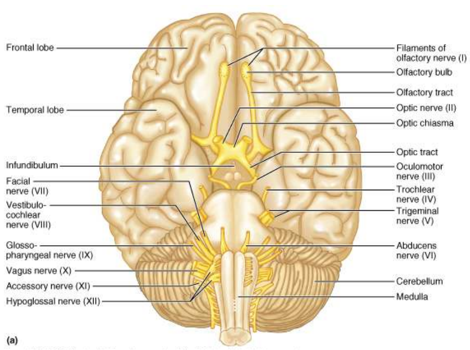


Figure 13.28a

Summary of Function of Cranial Nerves

Cranial nerves I – XII	Sensory function	Motor function	PS* fibers
I Olfactory	Yes (smell)	No	No
II Optic	Yes (vision)	No	No
III Oculomotor	No	Yes	Yes
IV Trochlear	No	Yes	No
V Trigeminal	Yes (general sensation)	Yes	No
VI Abducens	No	Yes	No
VII Facial	Yes (taste)	Yes	Yes
VIII Vestibulocochlear	Yes (hearing and balance)	No	No
IX Glossopharyngeal	Yes (taste)	Yes	Yes
X Vagus	Yes (taste)	Yes	Yes
XI Accessory	No	Yes	No
XII Hypoglossal	No	Yes	No

(b) *PS = parasympathetic

Figure 13.28b

Cranial Nerve I: Olfactory

- Arises from the olfactory epithelium
- Passes through the cribriform plate of the ethmoid bone
- Fibers run through the olfactory bulb and terminate in the primary olfactory cortex
- Functions solely by carrying afferent impulses for the sense of smell

Cranial Nerve I: Olfactory

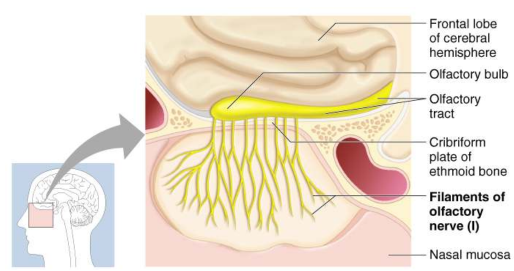
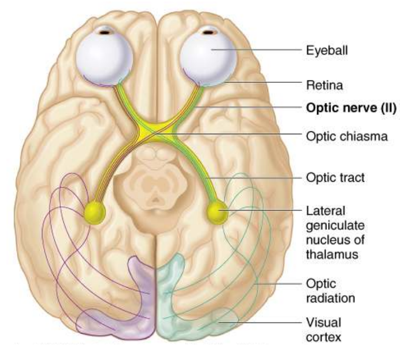


Table 13.2(I)

Cranial Nerve II: Optic

- Arises from the retina of the eye
- Optic nerves pass through the optic canals and converge at the optic chiasm
- They continue to the thalamus where they synapse
- From there, the optic radiation fibers run to the visual cortex
- Functions solely by carrying afferent impulses for vision

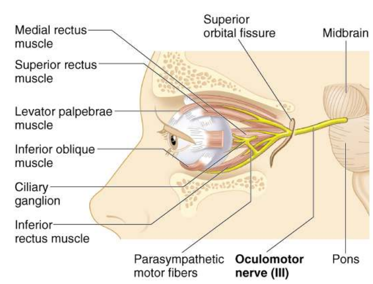
Cranial Nerve II: Optic



Cranial Nerve III: Oculomotor

- Fibers extend from the ventral midbrain, pass through the superior orbital fissure, and go to the extrinsic eye muscles
- Functions in raising the eyelid, directing the eyeball, constricting the iris, and controlling lens shape

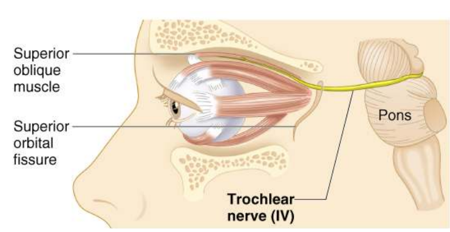
Cranial Nerve III: Oculomotor



Cranial Nerve IV: Trochlear

- Fibers emerge from the dorsal midbrain and enter the orbits via the superior orbital fissures; innervate the superior oblique muscle
- Primarily a motor nerve that directs the eyeball

Cranial Nerve IV: Trochlear



Cranial Nerve V: Trigeminal

- Composed of three divisions: ophthalmic (V_1), maxillary (V_2), and mandibular (V_3)
- Fibers run from the face to the pons via the superior orbital fissure (V_1), the foramen rotundum (V_2), and the foramen ovale (V_3)
- Conveys sensory impulses from various areas of the face (V_1) and (V_2), and supplies motor fibers (V_3) for mastication

Cranial Nerve V: Trigeminal

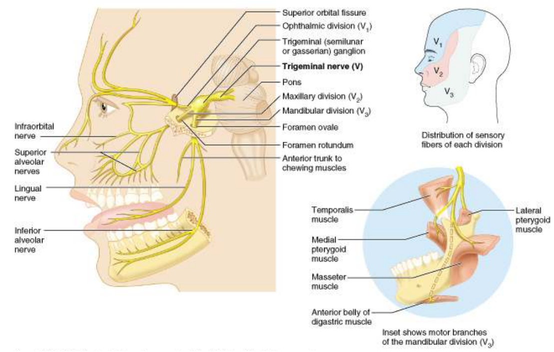


Table 13.2(V)

Cranial Nerve VI: Abducens

- Fibers leave the inferior pons and enter the orbit via the superior orbital fissure
- Primarily a motor nerve innervating the lateral rectus muscle

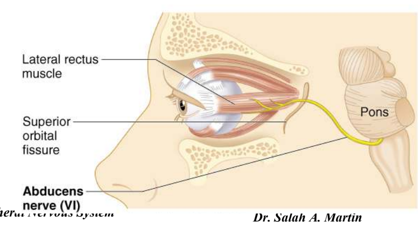


Table 13.2(VI)

Cranial Nerve VII: Facial

- Fibers leave the pons, travel through the internal acoustic meatus, and emerge through the stylomastoid foramen to the lateral aspect of the face
- Mixed nerve with five major branches
- Motor functions include facial expression, and the transmittal of autonomic impulses to lacrimal and salivary glands
- Sensory function is taste from the anterior two-thirds of the tongue

Cranial Nerve VII: Facial

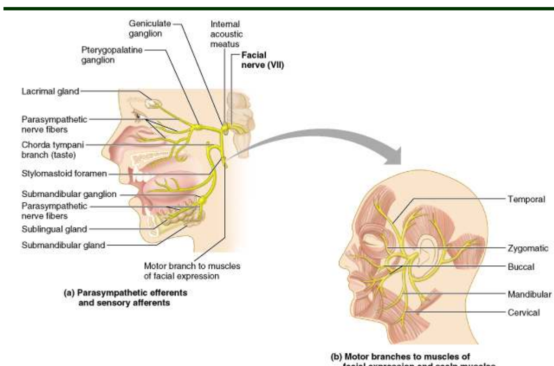
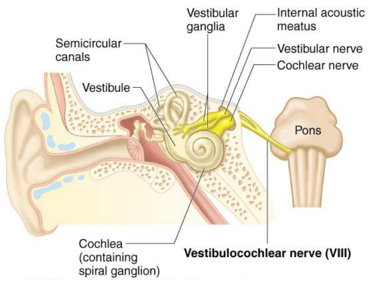


Table 13.2(VII)

Cranial Nerve VIII: Vestibulocochlear

- Fibers arise from the hearing and equilibrium apparatus of the inner ear, pass through the internal acoustic meatus, and enter the brainstem at the pons-medulla border
- Two divisions – cochlear (hearing) and vestibular (balance)
- Functions are solely sensory for the sense of equilibrium and of hearing

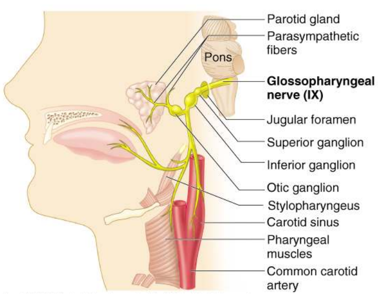
Cranial Nerve VIII: Vestibulocochlear



Cranial Nerve IX: Glossopharyngeal

- Fibers emerge from the medulla, leave the skull via the jugular foramen, and run to the throat
- Nerve IX is a mixed nerve with motor and sensory functions
- Motor – innervates part of the tongue and pharynx, and provides motor fibers to the parotid salivary gland
- Sensory – fibers conduct taste and general sensory impulses from the tongue and pharynx

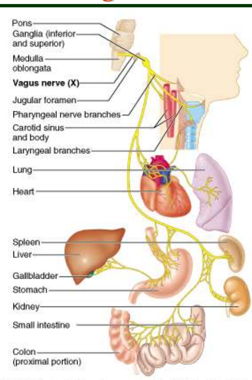
Cranial Nerve IX: Glossopharyngeal



Cranial Nerve X: Vagus

- The only cranial nerve that extends beyond the head and neck
- Fibers emerge from the medulla and emerge via the jugular foramen
- The vagus is a mixed nerve
- Most motor fibers are parasympathetic fibers to the heart, lungs, and visceral organs
- Its sensory function is in taste

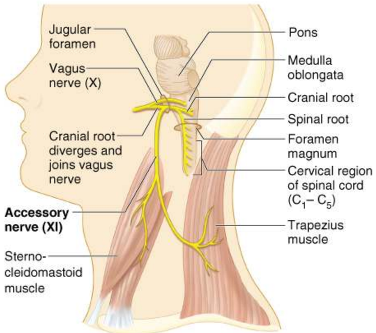
Cranial Nerve X: Vagus



Cranial Nerve XI: Accessory

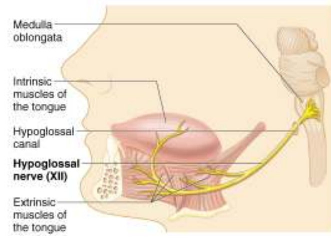
- Formed from a cranial root emerging from the medulla and a spinal root arising from the superior region of the spinal cord
- The spinal root passes upward into the cranium via the foramen magnum
- The accessory nerve leaves the cranium via the jugular foramen
- Primarily a motor nerve supplying:
  - Fibers to the larynx, pharynx, and soft palate
  - Innervates the trapezius and sternocleidomastoid, which move the head and neck

Cranial Nerve XI: Accessory



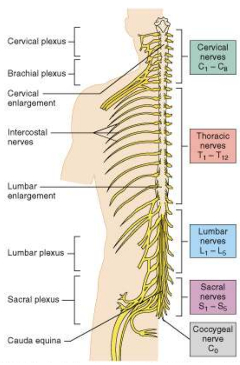
Cranial Nerve XII: Hypoglossal

- Fibers arise from the medulla and exit the skull via the hypoglossal canal
- Innervates both extrinsic and intrinsic muscles of the tongue, which contribute to swallowing and speech



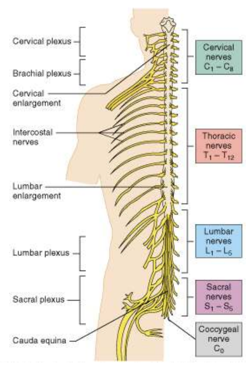
Spinal Nerves

- Thirty-one pairs of mixed nerves arise from the spinal cord and supply all parts of the body except the head



Spinal Nerves

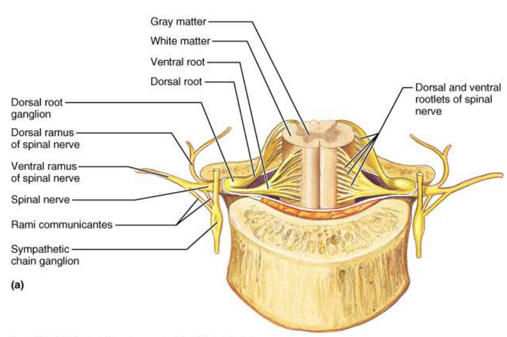
- They are named according to their point of issue
  - 8 Cervical (C_1–C_8)
  - 12 Thoracic (T_1–T_{12})
  - 5 Lumbar (L_1–L_5)
  - 5 Sacral (S_1–S_5)
  - 1 Coccygeal (C_0)



Spinal Nerves: Roots

- Each spinal nerve connects to the spinal cord via two medial roots
- Each root forms a series of rootlets that attach to the spinal cord
- Ventral roots arise from the anterior horn and contain motor (efferent) fibers
- Dorsal roots arise from sensory neurons in the dorsal root ganglion and contain sensory (afferent) fibers

Spinal Nerves: Roots



Spinal Nerves: Rami

- The short spinal nerves branch into three or four mixed distal rami
  - Small dorsal ramus
  - Larger ventral ramus
  - Tiny meningeal branch
  - Rami communicantes at the base of the ventral rami in the thoracic region

Nerve Plexuses

- All ventral rami except T_2–T_{12} form interlacing nerve networks called *plexuses*
- Plexuses are found in the cervical, brachial, lumbar, and sacral regions
- Each resulting branch of a plexus contains fibers from several spinal nerves

Nerve Plexuses

- Fibers travel to the periphery via several different routes
- Each muscle receives a nerve supply from more than one spinal nerve
- Therefore damage to one spinal segment cannot completely paralyze a muscle

Spinal Nerve Innervation: Back, Anterolateral Thorax, and Abdominal Wall

- The back is innervated by dorsal rami via several branches
- The thorax is innervated by ventral rami T_1–T_{12} as intercostal nerves
- Intercostal nerves supply muscles of the ribs, anterolateral thorax, and abdominal wall

Spinal Nerve Innervation: Back, Anterolateral Thorax, and Abdominal Wall

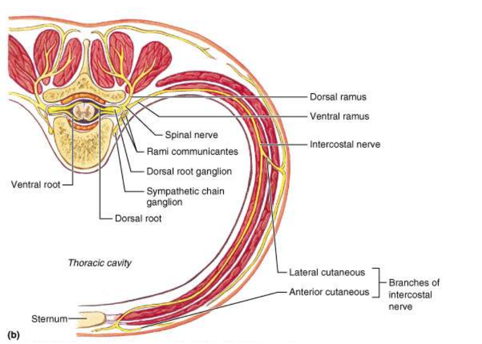


Figure 13.29c

Cervical Plexus

- The cervical plexus is formed by ventral rami of C_1–C_4
- Most branches are cutaneous nerves of the neck, ear, back of head, and shoulders

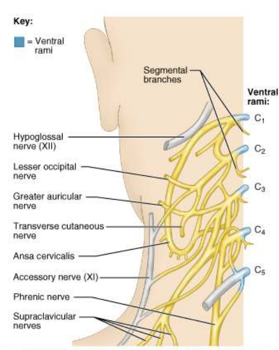


Figure 13.30

Cervical Plexus

- The most important nerve of this plexus is the phrenic nerve
  - The phrenic nerve is the major motor and sensory nerve of the diaphragm

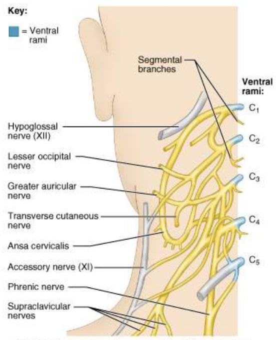


Figure 13.30

Brachial Plexus

- Formed by C_5–C_8 and T_1 (C_4 and T_2 may also contribute to this plexus)
- Gives rise to the nerves that innervate the upper limb
- There are four major branches of this plexus
  - Roots – five ventral rami (C_5–T_1)
  - Trunks – upper, middle, and lower, which form divisions
  - Divisions – anterior and poster serve the front and back of the limb
  - Cords – three fiber bundles: lateral, medial, and posterior

Brachial Plexus

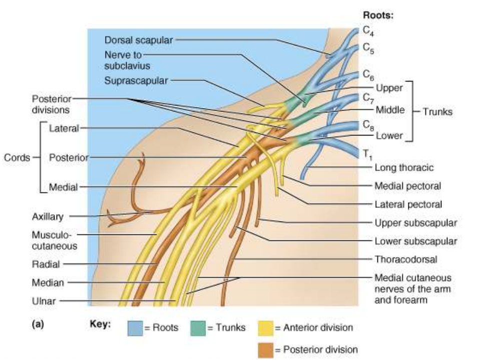


Figure 13.31a

Brachial Plexus: Distribution of Nerves

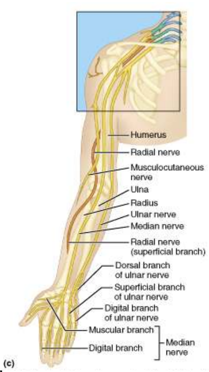


Figure 13.31c

Brachial Plexus: Nerves

- Axillary – innervates the deltoid and teres minor
- Musculocutaneous – sends fibers to the biceps brachii and brachialis
- Median – branches to most of the flexor muscles of arm
- Ulnar – supplies the flexor carpi ulnaris and part of the flexor digitorum profundus
- Radial – innervates essentially all extensor muscles

Brachial Plexus: Nerves

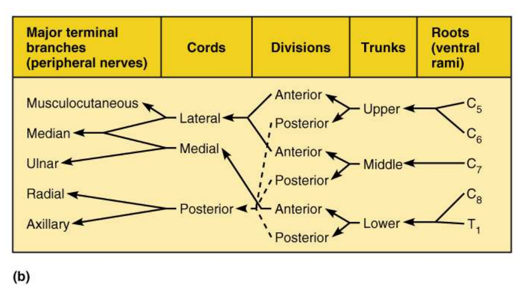


Figure 13.31b

Lumbar Plexus

- Arises from L_1–L_4 and innervates the thigh, abdominal wall, and psoas muscle
- The major nerves are the femoral and the obturator

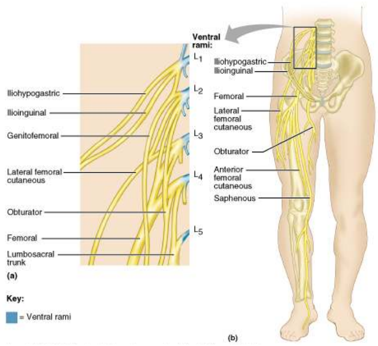


Figure 13.32

Sacral Plexus

- Arises from L_4–S_4 and serves the buttock, lower limb, pelvic structures, and the perineum
- The major nerve is the sciatic, the longest and thickest nerve of the body
- The sciatic is actually composed of two nerves: the tibial and the common fibular (peroneal) nerves

Sacral Plexus

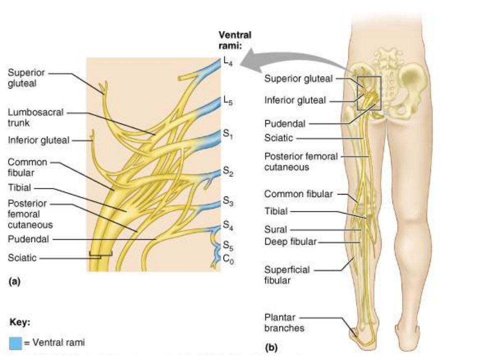


Figure 13.33

Innervation of Joints

- Hilton's law: any nerve serving a muscle that produces movement at a joint also innervates the joint itself and the skin over the joint

Dermatomes

- A dermatome is the area of skin innervated by the cutaneous branches of a single spinal nerve
- All spinal nerves except C_1 participate in dermatomes

Dermatomes

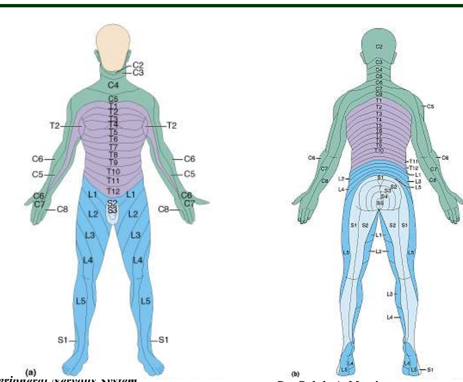


Figure 13.34

Motor Endings

- PNS elements that activate effectors by releasing neurotransmitters at:
  - Neuromuscular junctions
  - Varicosities of visceral effectors, smooth and cardiac muscle, and visceral glands

Innervation of Skeletal Muscle

- Terminals of somatic motor fibers that innervate voluntary muscles form neuromuscular junctions with their effector cells
- Axonal terminals contain synaptic vesicles filled with ACh
- ACh is released by exocytosis, diffuses across the synaptic cleft, and attaches to ACh receptors on the sarcolemma
- This binding stimulates a series of events that causes the muscle to contract

Innervation of Visceral Muscle and Glands

- Autonomic motor neurons branch, forming synapses with their effector cells
- Axonal terminals serving smooth muscle or glands exhibit varicosities
  - The vesicles contain ACh or norepinephrine
  - The synaptic cleft is always wider than that at somatic neuromuscular junctions

Three Levels of Motor Control

- Segmental level – circuits control locomotion and specific oft-repeated motor activity
- Projection level – helps control reflex and fixed-pattern activity
- Precommand level – starts and stops movement, coordinates movement with posture, blocks unwanted movement, and monitors muscle tone

Reflexes

- A reflex is a rapid, predictable motor response to a stimulus
- Reflexes may:
  - Be inborn or learned (acquired)
  - Involve only peripheral nerves and the spinal cord
  - Involve higher brain centers as well

Reflex Arc

- There are five components of a reflex arc
  - Receptor – site of stimulus
  - Sensory neuron – transmits the afferent impulse to the CNS
  - Integration center – either monosynaptic or polysynaptic region within the CNS
  - Motor neuron – conducts efferent impulses from the integration center to an effector
  - Effector – muscle fiber or gland that responds to the efferent impulse

Reflex Arc

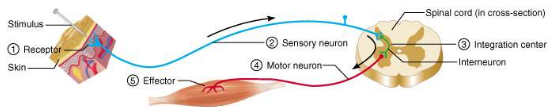


Figure 13.35

Stretch and Deep Tendon Reflexes

- For skeletal muscles to perform normally:
  - The muscle spindles and the Golgi tendon organs (proprioceptors) must constantly inform the brain as to the state of the muscle
  - Stretch reflexes initiated by muscle spindles must maintain healthy muscle tone

Muscle Spindles

- Composed of 3–10 intrafusal muscle fibers that lack myofilaments in their central regions, are noncontractile, and serve as receptive surfaces
- Muscle spindles are wrapped with two types of afferent endings: primary sensory endings of type Ia fibers and secondary sensory endings of type II fibers
- These regions are innervated by gamma (γ) efferent fibers
- Note: contractile muscle fibers are extrafusal fibers and are innervated by alpha (α) efferent fibers

Muscle Spindles

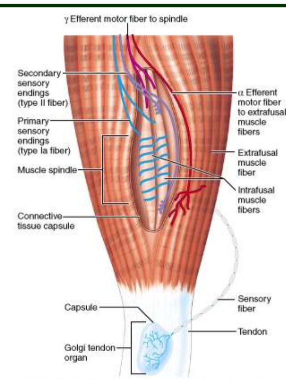


Figure 13.36

Operation of the Muscle Spindles

- Stretching the muscles activates the muscle spindle
  - There is an *increased* rate of action potential in Ia fibers

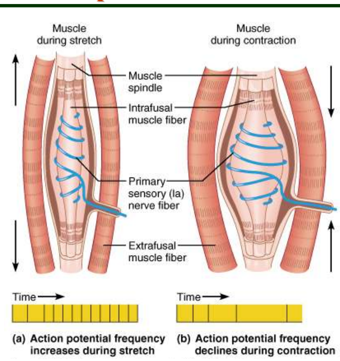


Figure 13.37

Operation of the Muscle Spindles

- Contracting the muscle reduces tension on the muscle spindle
  - There is a *decreased* rate of action potential on Ia fibers

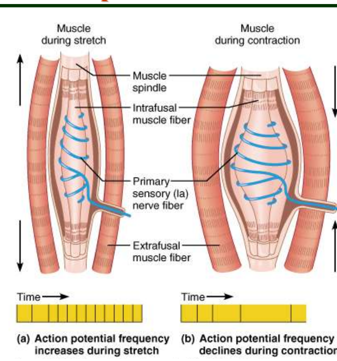


Figure 13.37

Stretch Reflex

- Stretching the muscle activates the muscle spindle
- Excited γ motor neurons of the spindle cause the stretched muscle to contract
- Afferent impulses from the spindle result in inhibition of the antagonist
- Example: patellar reflex
  - Tapping the patellar tendon stretches the quadriceps and starts the reflex action
  - The quadriceps contract and the antagonistic hamstrings relax

Stretch Reflex

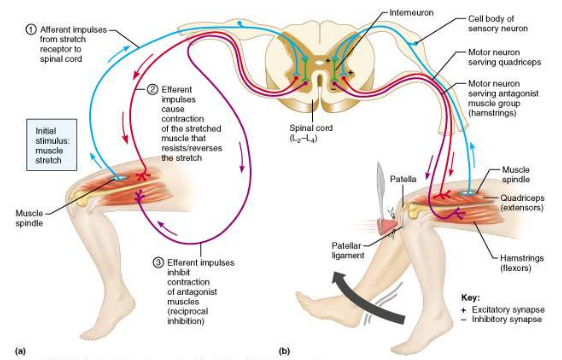


Figure 13.38

Deep Tendon Reflex

- The opposite of the stretch reflex
- Contracting the muscle activates the Golgi tendon organs
- Afferent Golgi tendon neurons are stimulated, neurons inhibit the contracting muscle, and the antagonistic muscle is activated
- As a result, the contracting muscle relaxes and the antagonist contracts

Flexor and Crossed Extensor Reflexes

- The flexor reflex is initiated by a painful stimulus (actual or perceived) that causes automatic withdrawal of the threatened body part
- The crossed extensor reflex has two parts
  - The stimulated side is withdrawn
  - The contralateral side is extended

Crossed Extensor Reflex

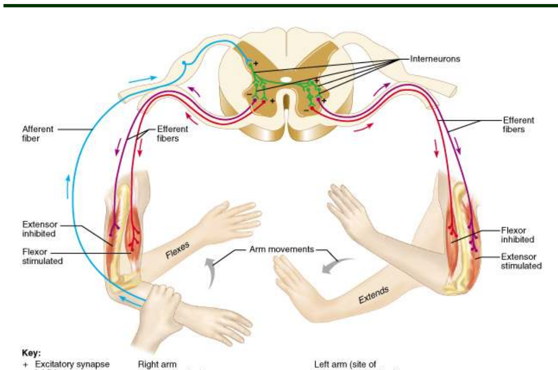


Figure 13.39

Superficial Reflexes

- Initiated by gentle cutaneous stimulation
- Example
  - Plantar reflex is initiated by stimulating the lateral aspect of the sole of the foot
  - The response is downward flexion of the toes
  - Indirectly tests for proper corticospinal tract functioning
  - Babinski's sign: abnormal plantar reflex indicating corticospinal damage where the great toe dorsiflexes and the smaller toes fan laterally